CONVEYOR BELT FLAMMABILITY STUDIES

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ABSTRACT

The U.S. Bureau of Mines conducted flammability tests of synthetic rubber and polyvinyl chloride conveyor belts in a large-scale fire gallery and a laboratory-scale ventilated tunnel. The gallery was 27-m-long, 3.8-m-wide and, 2.5-m-high with a 7.5-m-square cross-sectional area. For the gallery tests, 9.1-m-lengths of belting were placed on the top rollers of a conveyor frame and thermocouples installed to measure flame spread rates. The airflow was 1.52 m/s and the ignition source was a liquid fuel tray fire. The laboratory-scale tests were conducted in a 1.8-m-long by 0.46-m-square insulated tunnel at an airflow of 1.02 m/s. A 1.52-m-long by 0.23-m-wide belt sample, fastened to a metal rack, was used and the igniter was a 12-jet gas torch applied to the upstream end. A belt was judged to have passed the gallery test if a portion of the sample was undamaged. The same criterion was also applied to the laboratory-scale tunnel test. Of 21 belts examined, 1 belt that underwent surface charring in the gallery test and failed, passed the tunnel test and another belt that passed the gallery test, failed the tunnel test. The results for the remaining 19 belts were in complete agreement.

INTRODUCTION

A conveyor belt fire in an underground coal mine is a serious threat to life and property. To minimize the hazard of belt fires, the U.S. Code of Federal Regulations for underground coal mines requires approved fire-resistant belting, automatic fire suppression systems for belt conveyor drive areas, automatic fire sensor and warning device systems along belt haulageways, waterlines installed parallel to the entire length of belt conveyors, belt slippage and sequence switches, and special ventilation requirements along belt haulage entries (U.S. Code of Federal Regulations, Part 75, 1988). Despite these precautions, about 25% of the reportable U.S. underground coal mine fires from 1983 through 1988 - fires lasting more than half an hour after discovery, or causing injury - involved conveyor belting. In one instance, a belt fire destroyed the belting along 370 meters of belt entry in less than 24 hours, with one fatality caused by a stress induced heart attack from fighting the fire (Bondra 1987). In another case, a fire starting in the drive area of a belt line spread rapidly and resulted in sealing and abandonment of the entire mine (Strahin 1990).

The current U.S. flammability test for acceptance of fire-resistant belting for underground coal mines is specified in the Code of Federal Regulations (U.S. Code of Federal Regulations, Part 18, 1988) and is conducted by the U.S. Department of Labor, Mine Safety and Health Administration (MSHA). The test is performed in a 0.53 m cubical test chamber using 4 samples 152-mm-long by 12.7-mm-wide by the belt thickness. The sample is positioned horizontally in the chamber, with the transverse axis inclined at 45°, and one end exposed to the flame from a Bunsen type burner for 1 min in still air. At the end of 1 min, the burner flame is removed and the ventilating fan turned on to give an air current of 1.52 m/s. The duration of the belt flame/glowing is measured. A belt passes the test if 4 samples of the same belt do not exhibit either duration of flame exceeding an average of 1 min, or afterglow exceeding an average of 3 min duration. Because of the nature of this small-scale test, it is impossible to predict the flammability behavior of the belting under realistic large-scale test conditions.

Several other countries employ more severe large-scale flammability belt tests, such as the German inmine gallery test and the propane grid gallery test (Anderson 1986 and Green 1984). Belt fire damage is used as a pass/fail criterion for these tests. Heyn and Linhart (Heyn 1983) demonstrated the difficulty in correlating the German gallery test with several laboratory-scale fire tests and concluded that the large-scale gallery test could not be discontinued. The advantages of developing a simple laboratory-scale fire test for conveyor belting that would reproduce large-scale fire gallery results are obvious in cost and time saved. Such a test could readily be used by approval agencies, flammability testing laboratories and conveyor belt manufacturers to reliably evaluate fire-resistant belting.

This paper describes a study conducted by the U.S. Bureau of Mines, in cooperation with MSHA, to assess the flammability behavior of conveyor belting in a large-scale gallery test. The results were also utilized to develop an improved laboratory-scale ventilated tunnel fire test for belting.

LARGE-SCALE FIRE GALLERY TEST

The large-scale fire gallery test was conducted in the Bureau of Mines surface fire gallery located at Lake Lynn Laboratory. The fire gallery consists of a 27.4-m-long tunnel constructed of masonry block walls, a metal arched roof, and a concrete floor. The tunnel is coupled to a 1.8-m-diameter, 3500-m^3/min axivane fan via a 6-m-long tapered transition section. The ventilation flow can be varied between 0.5 m/s and 10 m/s by adjusting the pitch of the fan blades and/or by throttling the fan intake. A schematic of the gallery is shown in figure 1. The cross-sectional area of the tunnel is 7.5 m^2. The interior walls and roof of the tunnel are covered with ceramic blanket insulation. Except where noted, tunnel distances are measured from the junction of the fire tunnel and transition section, designated as the 0-meter mark. A typical conveyor belt frame, 21-m-long and 1.5-m-wide, is centered in the tunnel. The frame consists of a 0.4-m-diameter tail pulley and 0.13-m-diameter troughed idler assemblies at 1.2-m intervals.

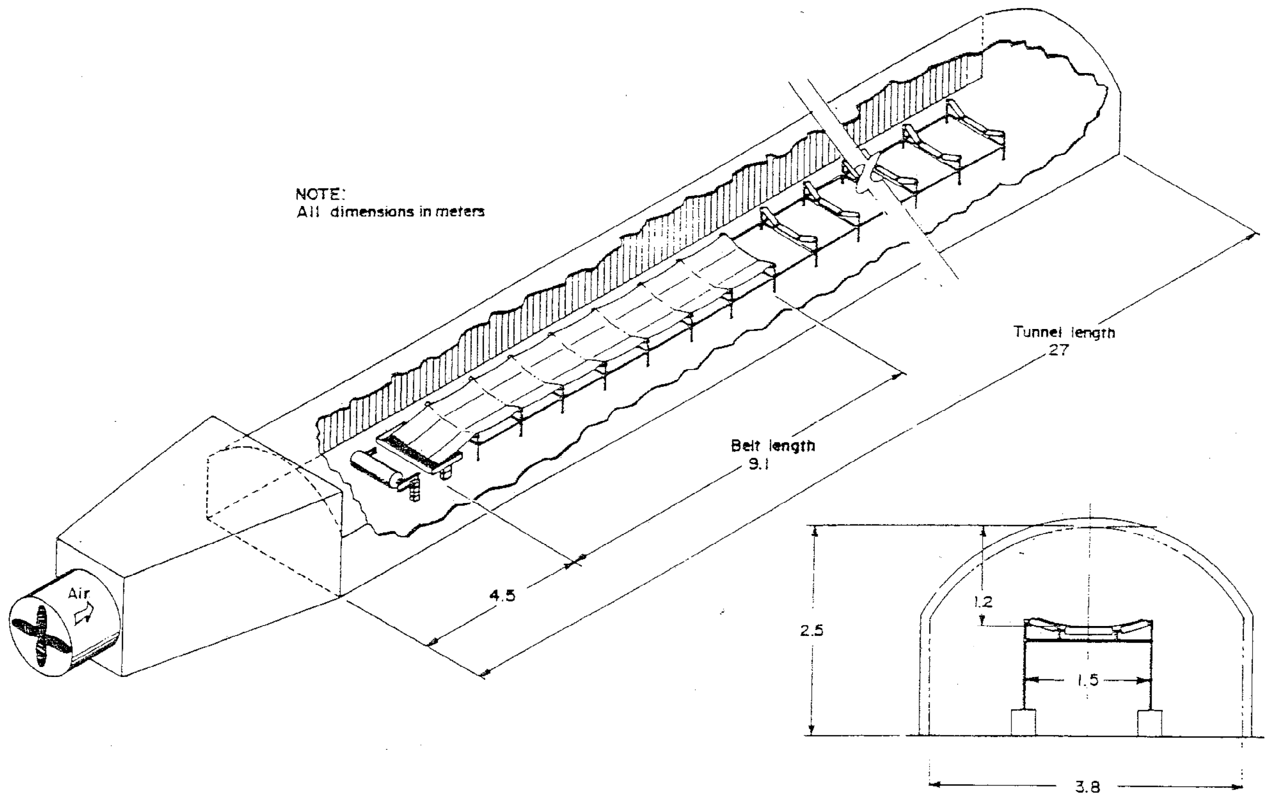

Figure 1. - Schematic of surface fire gallery.

A liquid fuel tray fire is the ignition source. The tray, 0.6-m-long by 1-m-wide by 0.3-m-deep, is just downstream of the tail pulley at a tunnel distance of 4.5 m and elevated 20 cm above the floor. The tray contains water on which fuel is floated. The ignition region is shielded from the ventilation flow by a steel plate and concrete blocks.

The gallery is instrumented with thermocouples to measure belt and gas temperatures. An array of 12 thermocouples, connected in parallel and distributed over the cross-sectional area of the tunnel, is located at 23.4 m to measure the average temperature of the stratified gas exit stream.

For these tests, a 9.1-m-length of conveyor belting was cut from a roll, weighed, and bare beaded thermocouples embedded just below the top surface of the belt. The thermocouples were positioned at equally spaced distances from one end of the belt sample along the center line and near each edge. Typically, 20 belt thermocouples were used to monitor belt temperatures and calculate flame spread rates. The belt sample was then placed on the rollers of the conveyor belt frame with the top (load carrying) cover up, if applicable, and one end bent downward into the shielded ignition area. The distance of the belting from the tunnel roof was about 1.2 m.

The tunnel airflow was adjusted to 1.52 m/s. The airflow was measured by a handheld vane anemometer at three locations along the sample length at a height of 25 cm above the belt. The average airflow near the exit of the tunnel was also measured. The airflow fluctuated slightly, but was within ± 10% of the set value.

Previous studies in the gallery on the effect of ventilation on conveyor belt fires (Lazzara 1987 and Verakis 1988) demonstrated that flame propagation at these test conditions was most likely to occur at an airflow of 1.52 m/s.

A fuel mixture of 1.9 L of unleaded gasoline and 5.7 L of kerosene was poured into the ignition tray. The tray fire with this fuel loading (7.6 L) burned for 5 to 6 min, with a peak fire size of about 700 kW. The flames enveloped the top and bottom surfaces of about 1.5 m of belting.

BELT SAMPLES

Thirteen synthetic rubber (R) belts and 8 polyvinyl chloride (P) belts were tested. Table I describes the belting. All the belts, except R3 and R7, were new. Belts R3 and R7 were obtained from mines and were slightly worn.

Table I: Conveyor Belting Description

Belt	Construction	Width, m	Thickness, mm	Weight, kg/linear-m
R1	4-plies SBR[1]	1.07	15	17.8
R2	4-plies SBR	1.07	13	16.9
R3	4-plies SBR	1.02	14	18.6
R4	chloroprene solid woven	1.07	9	14.3
R6	SBR solid woven	1.07	9	12.7
R7	3-plies SBR	1.16	12	17.8
R9	chloroprene/SBR[2] 3-plies	1.07	10	14.0
R10	chloroprene/SBR[2] solid woven	1.07	10	12.2
R11	3-plies SBR	1.07	11	14.9
R13	chloroprene/SBR 2-plies	1.02	7	11.7
R14	chloroprene/SBR 5-plies	1.00	19	24.1
R15	5-plies SBR/BR[3]	1.17	24	33.1
R17	2-plies SBR/BR	1.06	21	27.3
P1	PVC[4] solid woven	1.07	11	14.2
P2	Do.	1.07	11	13.8
P3	Do.	1.05	9	11.4
P4	Do.	1.07	10	13.9
P6	Do.	1.07	11	14.2
P7	Do.	1.07	13	18.6
P8	Do.	0.91	13	14.7
P9	PVC[5] solid woven with covers	1.22	13	21.9

[1]SBR - styrene-butadiene rubber

[2]Belts R9 and R10 contained the same ratio of chloroprene to SBR, but differed in construction.

[3]BR - butyl rubber

[4]PVC - polyvinyl chloride

[5]The PVC cover and carcass compounds were different blends.

All the belts, except R1 and R15, passed the current U.S. acceptance test for fire-resistant belting. Belts R1 and R15 are thus considered to be non-fire-resistant and would not be permitted in U.S. coal mines. However, they could be used in underground noncoal mines. Belts R4, R10, P2, P3, P4, P6 and P9 also passed the extended time (50 min) propane grid burner test.

RESULTS OF LARGE-SCALE GALLERY TEST

The results for the large-scale gallery test are given in table 2. The flame spread rates were determined from the time-temperature traces obtained from the belt thermocouples and the peak fire size was estimated from the temperature increase of the thermocouple array (Lazzara 1987). The time after the ignition of the tray fire at which the peak fire intensity occurred and the maximum gas temperature measured by a thermocouple near the roof at the exit of the tunnel are also given.

Four types of flammability behavior were observed: (1) rapid flame spread, >4m/min, followed by the entire sample burning, (2) rapid flame spread that charred the entire top surface of the belting, but left the bottom surface undamaged, (3) a slowly propagating flame, with spread rates ranging from 0.3 to 1.3 m/min, that completely consumed the belting (4) and a nonpropagating fire with a portion of the 9.1-m-long sample left undamaged.

Large quantities of smoke were generated by the burning belts, and vision was severely limited except for a narrow region near the gallery floor. Belt samples that were entirely consumed fell from the rollers and continued to burn on the floor; the residue usually consisted of ashes and small portions of badly charred belting.

Of the rubber belts tested, R1, R15 (non fire-resistant), R2, R3, R7, R9, R11, R13, and R17 were completely consumed by propagating fires, while R4 (chloroprene) and R10 (SBR-chloroprene blend, 1 ply) did not propagate flame and portions of the 9.1 m samples were undamaged. The entire top surface of belts R6 and R14 were lightly charred. For belt R2, the time-temperature traces obtained from the belt thermocouples are shown in figure 2.

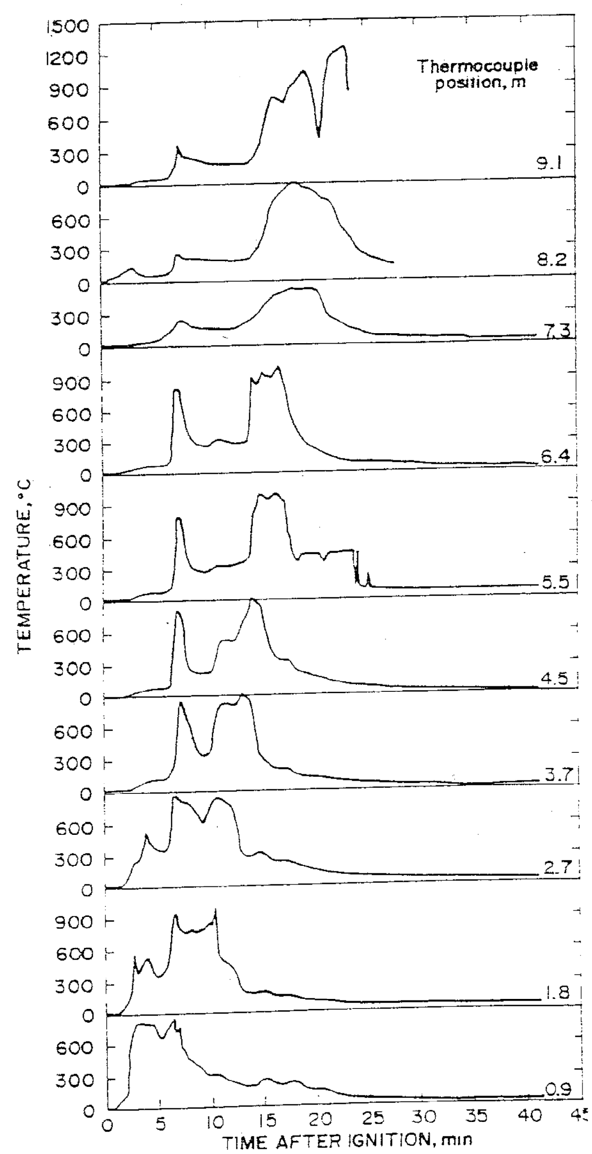

Figure 2. - Time-temperature traces of belt thermocouples for test of belt R2 at 1.52 m/s airflow.

Table II: Large-scale Fire Gallery Test Results for Synthetic Rubber and Polyvinyl Chloride Belts

Belt	Flame rate, m/min	Peak fire size (time), Mwatt (min)	Max gas temp.[1], °C	Belt damage[2], m	Pass or Fail[3]	Comments
R1	7.6	5.7 (12.0)	428	9.1	F	Rapid flame spread followed by entire sample destruction.
R2	0.9 (5.8)	3.9 (18.5)	330	9.1	F	Nonsustained rapid flame (5.8 m/min) followed by a steady propagating flame consuming belt.
R3	0.3	0.6 (25.5)	315	9.1	F	Slow steady propagating flame that consumed the belt.
R4	NP[4]	0.7 (4.5)	130	1.5	P	Nonpropagating flame that damaged belt in ignition zone.
R6	6.1	1.9 (3.8)	271	9.1	F	Rapid flame spread that lightly charred top surface of belt.
R7	4.6	6.3 (12.0)	448	9.1	F	Rapid flame spread followed by entire sample destruction.
R9	1.3	2.7 (13.5)	287	9.1	F	Slow flame spread that completely consumed belt sample.
R10	NP	1.3 (3.8)	163	2.4	P	Nonpropagating flame that damaged belt in ignition zone.
R11	5.4	5.1 (13.5)	391	9.1	F	Rapid flame spread followed by entire sample destruction.
R13	9.1	5.5 (4.9)	541	9.1	F	Rapid flame spread followed by entire sample destruction.
R14	8.7	1.90 (4.0)	293	8 (total sample)	F	Rapid flame spread that lightly charred top surface of belt.
R15	1.8 (9.1)	4.1 (21.0)	489	9.1	F	Nonsustained rapid flame (9.1 m/min) followed by a steady propagating flame consuming belt.
R17	7.9	2.4 (3.0)	342	9.1	F	Rapid flame spread followed by entire sample destruction.

Table II: Large-scale Fire Gallery Test Results for Synthetic Rubber and Polyvinyl Chloride Belts -- Continued

Belt	Flame rate, m/min	Peak fire size (time), Mwatt (min)	Max gas temp.[1], °C	Belt damage[2], m	Pass or Fail[3]	Comments
P1	6.7	3.0 (4.0)	394	9.1	F	Rapid flame spread followed by entire sample destruction.
P2	6.6	2.3 (4.8)	275	9.1	F	Rapid flame spread that deeply charred top surface of belt.
P3	NP	0.7 (4.3)	164	0.5	P	Nonpropagating flame that damaged belt in the ignition zone.
P4	9.1	2.0 (3.2)	411	9.1	F	Rapid flame spread that deeply charred top surface of belt.
P6	4.6	2.8 (2.8)	310	9.1	F	Rapid flame spread that deeply charred top surface of belt.
P7	NP	0.7 (4.0)	129	1.8	P	Nonpropagating flame that damaged belt in the ignition zone.
P8	NP	0.8 (4.5)	128	2.4	P	Nonpropagating flame that damaged belt in the ignition zone.
P9	NP	1.3 (5.0)	196	7.6	P	0.6 meter consumed and 7.0 meters charred on top surface.
TRAY FIRE		0.7 (5.0)	106	---	-	No belt, 7.6 liters of fuel.

[1]Gas temperature increase as measured near the roof at 27 m.
[2]Belt damage includes charring, but not blistering.
[3]The pass criterion is no fire damage across belt width at the end of sample.
[4]Nonpropagating flame; does not reach the end of the 9.1-m-long sample.

The tray fire ignited the belt, and a rapid flame spread (5.8 m/min) occurred over most of the top surface of the sample about 6 min after the start of the test. This initial flame, however, was not sustained but was followed by a steadily propagating flame front, with a rate of 0.9 m/min over the last 5 m of the sample, that destroyed the belting. The 9.1-m-long sample was totally consumed in about 25 min.

Of the polyvinyl chloride belts tested, P1 was entirely consumed, while the entire top surfaces of P2, P4, and P6 were deeply charred. Belts P3, P7, P8 and P9 did not propagate flame over the entire sample length, although for P9 the fire damage (light charring) extended to the 7.6 meter point, which was the maximum damage for any of the belts that passed the test. Several of the belts (R3, P1, P3, and P4) were tested more than once with similar results.

The simple criterion of belt fire damage, excluding blistering, was selected to decide whether a belt passed or failed the large-scale gallery test. A belt passed this gallery test if fire damage did not extend to the end of the 9.1-m-long sample and a portion of the sample was undamaged across its width. Applying this criterion to the results given in table II,15 of the 21 belts tested failed the large-scale gallery test and 6 passed.

LABORATORY-SCALE VENTILATED TUNNEL FIRE TEST

The laboratory-scale ventilated tunnel was similar to that proposed by the U.S. Bureau of Mines in an earlier study (Sapko 1981 and Perzak 1982) and is shown in figure 3. The test chamber is 1.8-m-long by 0.46 m square and is constructed from 2.5-cm-thick refractory material. The square chamber is connected to round exhaust ducting via a stainless steel transition section. The inner surface of the transition section is lined with a 13-mm-thick ceramic fiber blanket. The main exhaust is constructed from 30.5-cm-diameter galvanized steel ducting. The igniter is a commercial 12 jet methane gas burner (two rows of 6 jets). The belt sample is fastened to a steel rack constructed of slotted angle iron.

In preliminary experiments to establish a set of standard test conditions, several variables were examined, including airflow, sample width, distance of rack to tunnel roof, and burner duration. Several of the belts that exhibited different burning characteristics in the large-scale gallery test were used for these tests. The laboratory test conditions were adjusted to give similar fire damage results to the large-scale gallery test for these belts. The following test conditions were finalized: sample size,

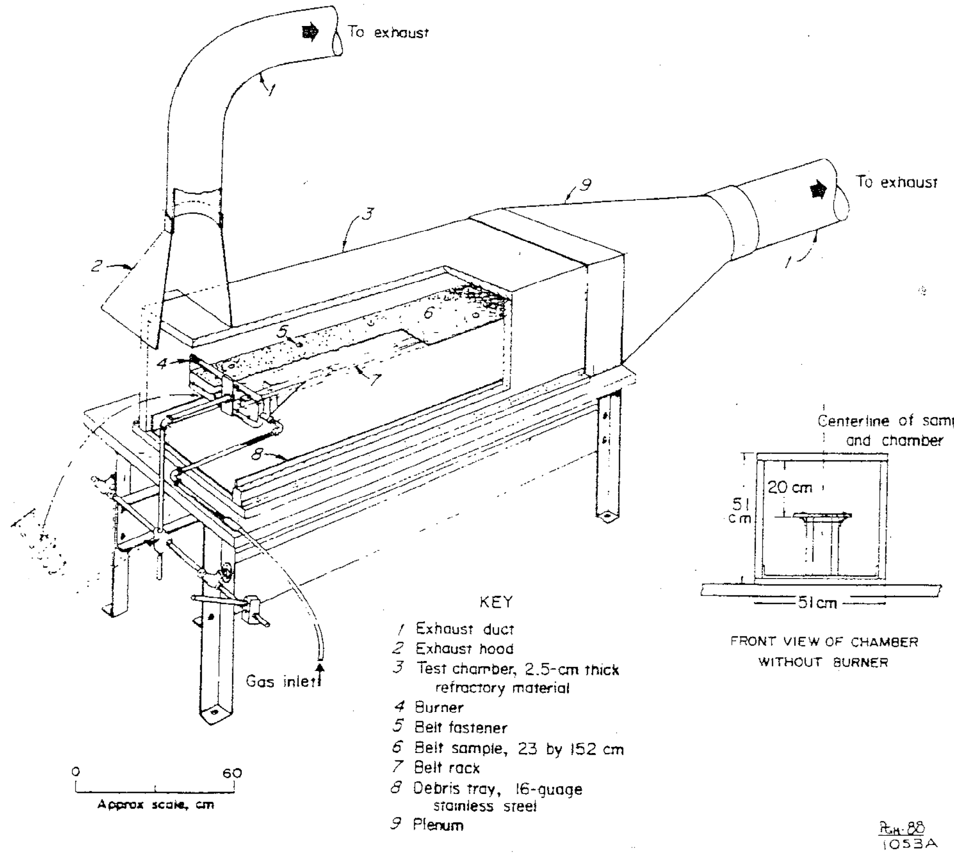

Figure 3. - Schematic of laboratory-scale fire tunnel.

1.52-m-long by 0.23-m-wide by belt thickness; distance of sample rack from tunnel roof, 20 cm; tunnel airflow, 1.02 m/s; duration of gas igniter, 5 min; methane flow to burner, 35 L/min at 22° C and 101 kPa.

To conduct a test, a belt sample is fastened with the top cover up, if applicable, to the steel rack with 1.4-mm-diameter cotter pins and thin washers to prevent the belt from shrinking away from the burner. The rack is placed in the tunnel and the airflow (1.02 m/s) set. The airflow is measured by a vane anemometer placed on the belt surface about 30 cm from the front of the tunnel. The methane burner is ignited and the flame allowed to stabilize. The burner is then applied to the front edge of the belt sample with the flames impinging equally on the top and bottom surfaces of the sample. After 5 min, the burner is removed, and the belt sample allowed to burn until the flames are out. If a portion of the sample remains on the rack, the rack is removed and the extent of any undamaged belting, across the width of the sample, is measured.

A belt is judged to have passed the laboratory-scale test if, in three trials, there remains a portion of the 1.52-meter-long sample that is undamaged across its width, excluding blistering. A belt fails the test if in any single trial, fire damage extends to the end of the sample.

RESULTS OF LABORATORY-SCALE VENTILATED TUNNEL FIRE TEST

All 21 belts that were examined in the large-scale fire gallery test were subjected to the laboratory-scale fire test described above. More than the required number of three trials were made for several of the belts, to check repeatability. The results are given in table III. For most of the belts, the fire damage was similar to that found in the large-scale fire gallery test.

Of the 13 rubber belts tested, 11 failed the laboratory-scale test by being totally consumed and 2 passed.

For the 8 polyvinyl chloride belts, 4 failed the laboratory-scale test (P1 by being totally consumed and P2, P4, and P8 due to charring) and 4 passed. The repeatability of the test results for the poor and very good fire-resistant belts (defined by total destruction or fire damage limited to the ignition area in the large-scale gallery test, respectively) was excellent.

COMPARISON OF LARGE-SCALE GALLERY AND LABORATORY-SCALE FIRE TEST RESULTS

A comparison of the pass/fail results of the large-scale gallery and laboratory scale fire tests for the 21 belts shows that they are in very good agreement. For the 13 rubber belts, the results are in complete agreement, with the same 11 belts failing the gallery and laboratory scale test, and 2 belts (R4 and R10) passing both tests. As noted earlier, belts R1 and R15 are non fire-resistant while the 11 other belts passed the current U.S. acceptance test for fire-resistant belting. Belts R4 and R10 also passed the extended time propane grid burner test. For the 8 polyvinyl chloride belts, the pass/fail results for 6 of the belts were the same, with 3 belts (P1, P2, P4) failing the large-scale gallery and laboratory-scale fire tests and 3 belts (P3, P7, P9) passing both tests. There are discrepancies in the comparison for belts P6 and P8.

Belt P6 failed the large-scale gallery test but passed the laboratory-scale test; belt P8 passed the large-scale test but failed the laboratory-scale test. As previously stated, all the polyvinyl chloride belts passed the current U.S. test for fire-resistant belting and belts P2, P3, P4, P6 and P9 also passed the extended time propane grid burner test. The two

Table III: Laboratory-scale Ventilated Tunnel Fire Test Results

Belt	Comments	Failure ratio[1]	Belt damage[2], m	Pass[3] or Fail
R1	Total belt destruction	1/1	1.52	F
R2	Do.	3/3	1.52	F
R3	Do.	3/3	1.52	F
R4	Top belt surface partially charred.	0/6	0.91	P
R6	Total belt destruction.	1/1	1.52	F
R7	Do.	1/1	1.52	F
R9	Do.	2/2	1.52	F
R10	Top belt surface partially charred.	0/3	0.81	P
R11	Total belt destruction.	2/2	1.52	F
R13	Do.	1/1	1.52	F
R14	Do.	2/2	1.52	F
R15	Do.	1/1	1.52	F
R17	Do.	1/1	1.52	F
P1	Do.	3/3	1.52	F
P2	Top surface completely charred in one trial.	1/3	1.52	F
P3	Top belt surface partially charred.	0/5	0.89	P
P4	Top surface completely charred in one trial.	1/3	1.52	F
P6	Top belt surface partially charred.	0/3	1.04	P
P7	Do.	0/3	0.64	P
P8	Top surface completely charred in one trial.	1/3	1.52	F
P9	Top belt surface partially charred.	0/3	0.74	P

[1]The failure ratio is the number of samples that were damaged over the entire sample length (1.52 m) divided by the number of trials.
[2]The fire damaged length for the most extensively damaged sample in all the trials. Belt damage includes charring, but not blistering. For belts that charred, the top surface damage was always more extensive than bottom surface damage.
[3]The pass criterion is no fire damage across sample width at end of sample in 3 separate trials.

discrepancies are not completely understood; however, belt P6 sustained a greater amount of fire damage (1.04 m) than any other belt that passed the laboratory-scale test. Belt P8 was the narrowest belt (0.91-m-width) tested in the large-scale gallery and this may have influenced the results; a narrower belt would be more likely to pass the gallery test since energy losses from the burning belt would be more than for a wider belt, all else being equal.

Overall, of the 21 belts examined, there was agreement for 19 of the belts between the pass/fail results of the large-scale gallery test and the laboratory-scale tunnel test.

CONCLUSIONS

Based on the flammability data obtained from a large-scale gallery test of 21 conveyor belts, a relatively simple and inexpensive laboratory-scale fire test was developed for conveyor belting. The laboratory-scale test results were in very good agreement with those obtained in the large-scale gallery based solely on the criterion of belt fire damage. MSHA plans to replace the current conveyor belt flammability acceptance test with the Bureau's new laboratory-scale fire test for belting (minutes of public meeting, 1989). The rulemaking process for this change has been initiated.

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